Dynamic Sub-Channel Allocation in Multiuser OFDM Systems to Achieve Variable Data Rate

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Abstract - **This paper investigates the problem of dynamic multiuser subchannel allocation in the downlink OFDM systems. In traditional TDMA or FDMA systems, resource allocation for each user is non-adaptively fixed. Since the subchannel allocations among the users are not optimized, a group of users is likely to suffer from poor channel gains resulting from large path loss and random fading. To resolve this problem a low-complexity adaptive subchannel allocation algorithm is proposed in this paper. By adaptively assigning frequency subchannels, n take advantage of channel diversity among users in different locations, which is called Multiuser diversity. The capacity of MU-OFDM is maximized when each subchannel is assigned to the user with the best channel-to-noise ratio for that subchannel. However, fairness among the users cannot generally be achieved with such a scheme. In this paper, a set of proportional fairness constraints is imposed to assure that each user achieve a required data rate, that ensures quality of service. In the proposed algorithm, subchannel allocation is performed by assuming an equal power distribution.**

Index Terms - **OFDM, Sub-Channel, Multiuser, Variable Data Rate.**

I. Introduction

In the wireless environment, multipath propagation occurs due to many reflections of the transmitted signal. This leads to the reception of multiple replicas of delayed versions of the transmitted signal. As a consequence, fading and inter symbol interference (ISI) occur. If the data rate is low and the symbol duration is large as compared to the maximum delay of the channel, then ISI can be combated without any equalization. As the distance range or the data rate increases, ISI becomes more severe and channel equalization has to be provided, otherwise it imposes a constraint on the maximum achievable data rate [1-4]. Thus, the time-varying nature of wireless channel and its inherent randomness makes the choice of modulation technique very critical. So, the need of hour is to mitigate the effects of multi-path propagation so that high data rate applications as WLAN, DAB, and DVB etc. can be supported. This requirement implies a situation, where a high data rate is to be transmitted over a channel with a relatively large maximum delay. Such an ISI-immune and bandwidth-efficient communication system is given by the OFDM (Orthogonal Frequency Division Multiplexing) transmission technique. It is a wideband multi-carrier modulation technique in which a high-rate data stream is divided into a number of low-rate data streams and transmitted simultaneously over a number of orthogonal sub-carriers [5-6]. Thus, in each sub-channel, the symbol duration is long as compared to the maximum delay of the channel and ISI can be mitigated. The orthogonality of carriers makes the system bandwidth-efficient. It can be seen as either a modulation or a multiplexing technique. The OFDM signals are easily generated using FFT devices, but with some drawbacks as high peak-to-average power ratio (PAPR) and synchronization issues [7-8].

The common problem found in high speed communication is inter-symbol interference (ISI) which occurs when a transmission interferes with itself and the receiver cannot decode the transmission correctly. OFDM is especially suitable for high-speed communication due to its resistance to ISI. As communication systems increase their information transfer speed, the time for each transmission necessarily becomes shorter. Since the delay time caused by multipath remains constant, ISI becomes a limitation in high-data-rate communication. OFDM avoids this problem by sending many low speed transmissions simultaneously. This longer symbol duration leads to reduced problems with ISI [1].

The principle of the OFDM technique is to split a high-rate data stream into a number of lower rate streams, which are then simultaneously transmitted on a number of orthogonal subcarriers. As the symbol duration is increased for lower rate parallel streams, the relative amount of dispersion in time caused by multipath delay spread decreases. Moreover, the ISI can be almost completely eliminated by introducing a guard interval, which is a cyclic extension of the OFDM symbol [1].

In a multiuser OFDM system, each of the multiple users' signals may undergo independent fading because users may not be in the same locations. Therefore, the probability that all the users' signals on the same subcarrier are in deep fading is very low. Hence, for a specific subcarrier, if a user's signal is in deep fading, the others may not be in deep fading and the user in a good channel condition may be allowed to transmit data on that subcarrier yielding multiuser diversity effects [2].

OFDM allows digital data to be efficiently and reliably transmitted over a radio channel, even in multipath environments. OFDM transmits data by using a large number of narrow bandwidth carriers. These carriers are regularly spaced in frequency, forming a block of spectrum. The frequency spacing and time synchronization of the carriers is chosen in such a way that the carriers are orthogonal,

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meaning that they do not cause interference to each other. This is despite the carriers overlapping each other in the frequency domain. The term OFDM is derived from the fact that the digital data is sent using many carriers, each of a different frequency thereby leading to Frequency Division Multiplexing and these carriers are orthogonal to each other, hence the term used Orthogonal Frequency Division Multiplexing [1].

II. System Model

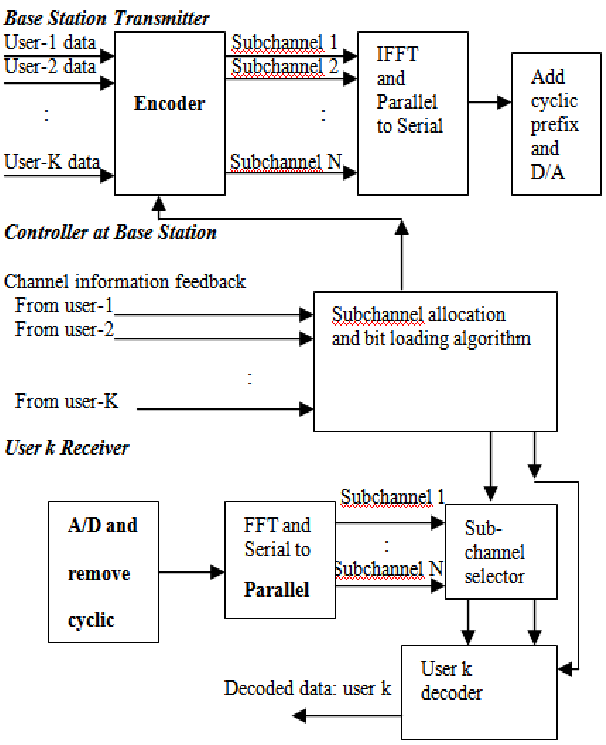

Fig. 1. Multiuser OFDM transmitter and receiver.

A multiuser OFDM system is shown in Fig. 1. This OFDM system consists of base station transmitter controller at base station and receiver. The transmitter section converts digital data to be transmitted, into a mapping of subcarrier amplitude and phase. It then transforms this spectral representation of the data into the time domain using an Inverse Fast Fourier Transform (IFFT). The receiver performs the reverse operation of the transmitter, mixing the RF signal to base band for processing, then using a Fast Fourier Transform (FFT) to analyze the signal in the frequency domain. The amplitude and phase of the subcarriers is then picked out and converted back to digital data.

At the base station, all channel information is sent to the subchannel allocation algorithm through feedback channels from all mobile users. The subchannel allocation made by the algorithm is forwarded to the OFDM transmitter at base station. The transmitter then selects different numbers of bits from different users to form an OFDM symbol. The subchannel allocation is updated as fast as the channel information is collected. Then, a perfect instantaneous channel information is assumed to be available at the base station. It is also assumed that the subchannel allocation information is sent to each user by a separate channel [3, 5].

Mathematically, the optimization problem considered in dynamic subchannel allocation is formulated as

$$\sum_{k=1}^{K}\sum_{n=1}^{N}\frac{\rho_{k,n}}{N}\log_2\left(1+\frac{p_{k,n}}{N_0}\frac{h_{k,n}^2}{\frac{B}{N}}\right) \qquad (1)$$

$$\text{subject to} \quad \sum_{k=1}^{K}\sum_{n=1}^{N} p_{k,n} \le P_{total}$$

$$p_{k,n} \ge 0 \quad \text{for all k,n}$$

$$\rho_{k,n} = \{0,1\} \quad \text{for all k,n}$$

$$\sum_{k=1}^{K}\rho_{k,n} = 1 \quad \text{for all n}$$

$$R_1 : R_2 : \ldots\ldots\ldots R_k = \lambda_1 : \lambda_2 : \ldots\ldots\ldots : \lambda_k$$

where

K is the total number of users,
N is the total number of subchannels,
N_0 is the power spectral density of AWGN,
B is the total available bandwidth.
P_{total} is the total available power.
$p_{k,n}$ is the power allocated for user k in the subchannel n
$h_{k,n}$ is the channel gain for user k in subchannel n, and $\tilde{n}_{k,n}$ can only be either 1 or 0, indicating whether subchannel n is used by user k or not.
λ_k is the system parameter for proportional rates.

The subchannel allocation is done first by assuming equal power distribution and then power distribution is done by water filling theorem.

The capacity for user *k*, denoted as R_k, which is defined as

$$R_k = \sum_{n=1}^{N}\frac{\rho_{k,n}}{N}\log_2\left(1+\frac{p_{k,n}}{N_0}\frac{h_{k,n}^2}{\frac{B}{N}}\right) \qquad (2)$$

$\{\lambda_i\}_{i=1}^{K}$ is a set of predetermined values that are used to ensure proportional fairness among users.
The fairness index is defined as

$$F = \frac{\left(\sum_{k=1}^{K}\gamma_k\right)^2}{K\sum_{k=1}^{K}\gamma_k^2} \qquad (3)$$

with the maximum value of 1 to be the greatest fairness case in which all users would achieve the same data rate. When all λ_i terms are equal, it is a special case of the proposed constrained-fairness problem [4, 6, 7].

III. Suboptimal Subchannel Allocation

In the suboptimal subchannel allocation algorithm, equal power distribution is assumed across all subchannels.

$$P_{k,tot} = \frac{P_{total}}{N}$$

where $P_{k,\,tot}$ =Total power allocated to user k.

$H_{k,n}$ is the channel-to-noise ratio for user *k* in subchannel *n* and defined by

$$H_{k,n} = \left(\frac{h_{k,n}^2}{N_0 \left(\frac{B}{N} \right)} \right)$$

Ω_k is the set of subchannels assigned to user *k*.

A flowchart is developed for implementing the suboptimal subchannel allocation as shown in Fig. 2. The suboptimal subchannel allocation achieved by, initializing the set capacity as R_k= 0, for k=1, 2, …., K and subchannels n={1,2,….,N}. Now, for users k = 1 to K, find the subchannel with highest channel-to-noise ratio from all subchannels from 1 to N. Update the capacity R_k. If all the subchannels are not allocated, then the process is repeated. In the mean time continue to find the user with lowest proportional capacity among all users. For found user, find the subchannel with highest channel-to-noise ratio from all subchannels, and update the capacity. With this algorithm the suboptimal subchannel allocation is achieved [4].

The principle of the suboptimal subchannel algorithm is for each user to use the sub channel with high channel-to-noise ratio as much as possible. At each iteration, the user with the lowest proportional capacity has the option to pick which subchannel to use. The subchannel allocation algorithm is suboptimal, because equal power distribution in all sub channels is assumed. After subchannel allocation, only coarse proportional fairness is achieved. The goal of maximizing the sum capacity while maintaining proportional fairness is achieved by the power allocation [4].

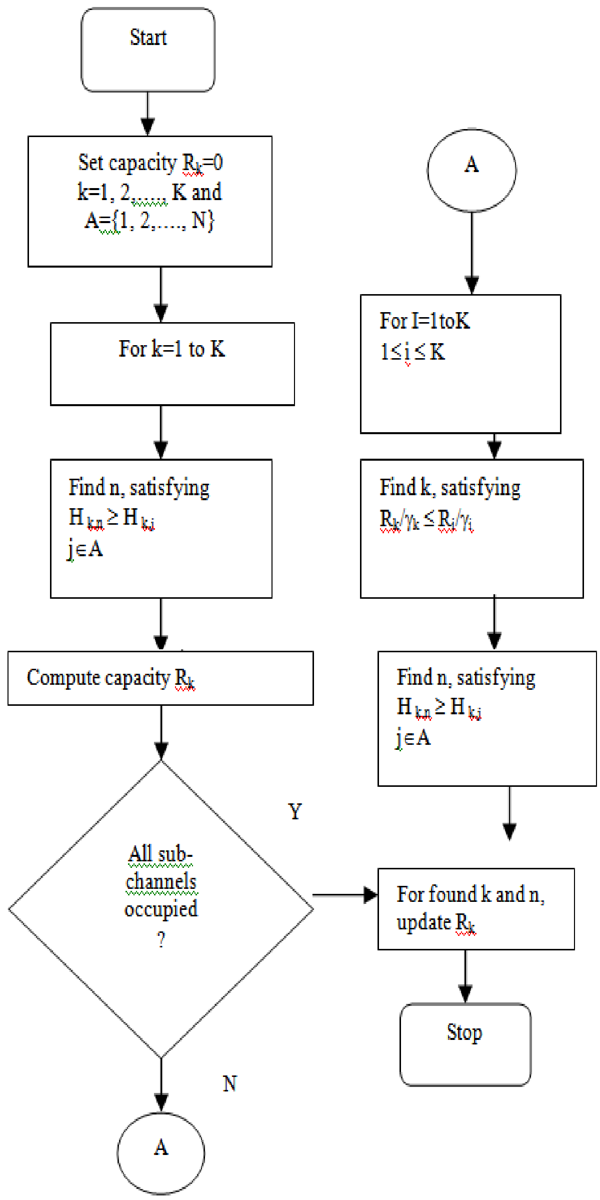

Fig. 2. Flowchart for suboptimal subchannel allocation.

IV. Results and Discussions

The algorithm developed in the previous section is coded on matlab platform. In this section simulation results are presented to show the performance of the proposed subchannel allocation algorithm.

The simulation is carried out for a system with number of subcannels N being 8, and the number of users K being 2. For the system parameter λ_1 and λ_2 being unity 1, the capacity of user-1 and user 2 is optimized using the above algorithm to

R_1= 4.9767 bits\s\Hz and

R_2= 4.477 bits\s\Hz

Similarly for the system parameter λ_1 = 1 and λ_2 = 2, the capacity of user-1 and user 2 is optimized as

R_1 =3.7701 bits\s

R_2 =5.5378 bits\s

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With proposed sub-channel allocation, the capacity is distributed very well amongst users according to the rate constraints. With $\gamma_1 = \gamma_2 = 1$, subchannels are distributed equally and the two users will achieve almost equal capacity. With and $\gamma_2 = 2$, user-2 gets more number of sub channels and hence achieves a significant capacity. The final results discussed above are tabulated as shown in Table I.

TABLE I
DATA RATES ACHIEVED BY PROPOSED SCHEME

User	Capacity in bits/s	Parameters for proportional rate γ
User-1	4.9767	1
User-2	4.477	1
User-1	3.7701	1
User-2	5.5378	2

V. Conclusion

The paper presents the results of a novel suboptimal adaptive subchannel allocation algorithm while maintaining proportional fairness among users. With this algorithm, a flexible and variable data rate distribution among users can be achieved. The proposed suboptimal algorithm with equal power distribution over all subchannels offers significant capacity gain over a non-adaptive TDMA resource allocation scheme.

$\gamma_1 = 1$

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